Direct CO2 and CH4 area wide anomalous gas detection using Remote Sensing

Area wide Monitoring and Verification of Possible CO2 and CH4 Leakage from Underground Storage Formations

We Use Airborne and Satellite High Resolution Imagery
The Test site for CO2 and CH4 release detection was
The Rocky Mountain Oil Field Testing Center (RMOTC)
Located At the NPR-3 Tea Pot Dome Oil field
In Casper Wyoming, USA

James Jacobson Jr., Eli A. Silver, William L. Pickles,
University of California Santa Cruz
Jeff Meyers NASA AMES

CCP2 Storage Monitoring and Verification Conference
May 06, 2007 Pittsburg, Pennsylvania

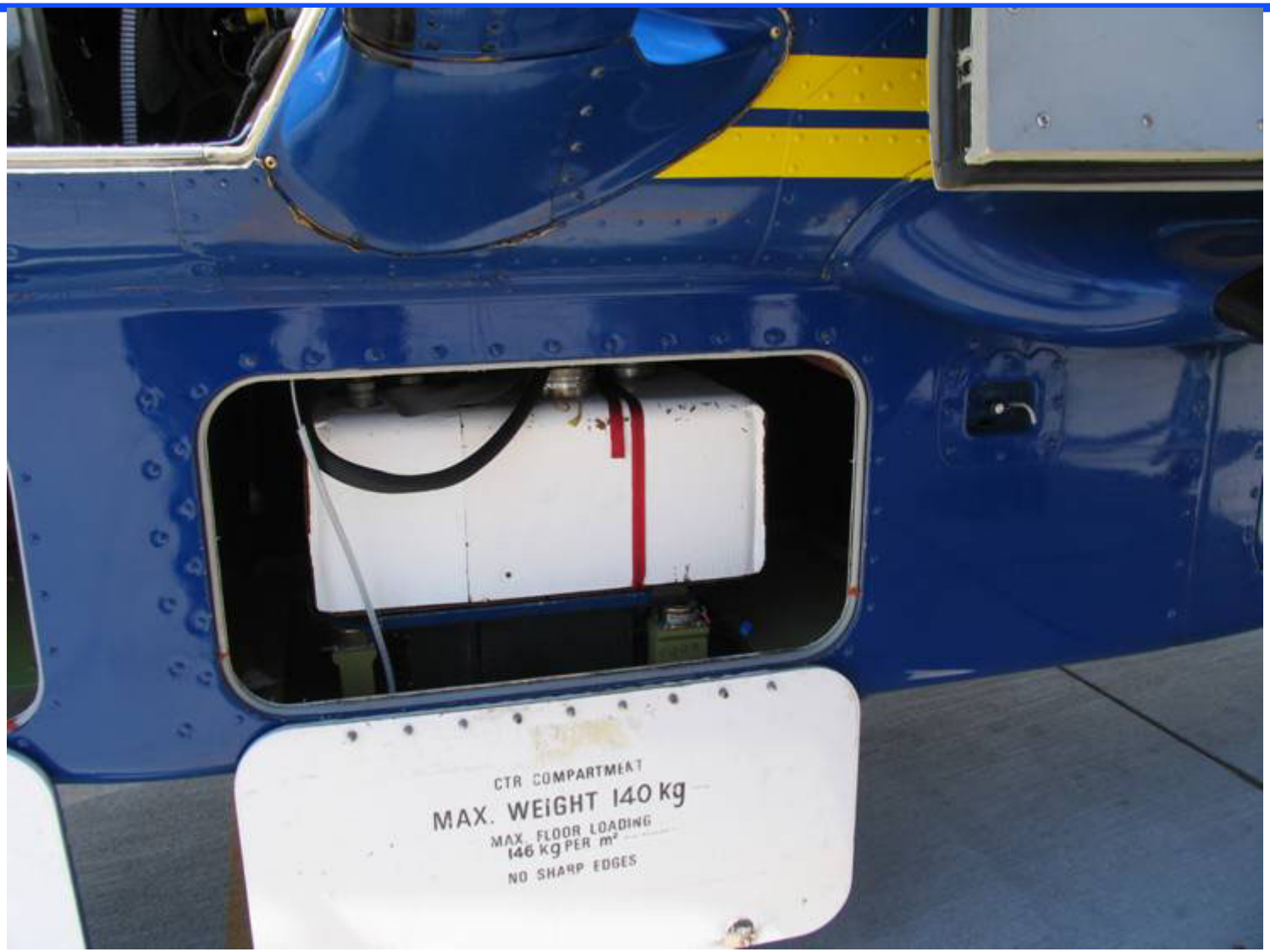
Direct imaging of gaseous CO2 and CH4 leakage for screening large areas above underground storage formations

- We have used the MASTER airborne passive multispectral flown by NASA AMES to image CO2 and CH4 gasses above ground leaks that we created at the RMOTC NPR3 test site
- If significant CO2 gas percolates up along faults, cracks, joints, or well heads from a storage formation below, it will create a local plume and increase the ambient CO2 in the whole region.
- CH4 is likely to accompany CO2 leakage from EOR fields, and coal bed fields
- The MASTER (Modis/ASTER Simulator) airborne multispectral imager was used to detect gaseous CO2 and CH4

NASA AMES Master airborne multispectral Imaging for CO2 and CH4 absorptions flown by Sky Research

MASTER control and acquisition System in the SKY Research Caravan aircraft

MASTER multispectral sensor in the Caravan photo bay



CO2 Leak Creation

Liquid CO2 was released from a long perforated pipe

Perforated PVC pipe releasing CO2 along 100 meters length simulating leaking along a fault

CO2 and CH4 release locations created at NPR-3 by RMOTC

This image created from the full run of MASTER at an elevation of ~1400m. Pixel size is roughly 1.5 square meters. All Seven leak points in the virtual pipeline are shown labeled and in unique colors.

		Lat (N)	Lon (W)		Lat (N)			Lon (W)				planned
MAP ID	GPS ID	Dec.Deg	Dec.Deg	Elev (ft)	Deg	Min	Sec	Deg	Min	Sec	Gas	Rate (cfh)
P5	POI003	43.34099	106.227	4974	43	20	27.7	106	13	36.3	CO2	300
Moved P4 to 2E	POI004	43.33688	106.228	5015	43	20	13.2	106	13	37.8	CH4	100
P3	POI005	43.32899	106.232	4999	43	19	44.5	106	13	51.5	CH4	400
5	POI006	43.29551	106.222	5240	43	17	44.1	106	13	15.8	CH4	5000
4*	POI007	43.27222	106.207	5252	43	16	20.1	106	12	24.6	CO2	800*
1	POI008	43.24820	106.187	5303	43	14	53.6	106	11	12.1	CH4	800
P1	POI009	43.30368	106.219	5168	43	18	12.7	106	13	6.3	CO2	5000
2E	POI010	43.31576	106.226	5117	43	19	15.51	106	13	41.89	CH4	100
		WAG84			NAD27							

*line leak setup aborted due to ice ~1524m
actual rate

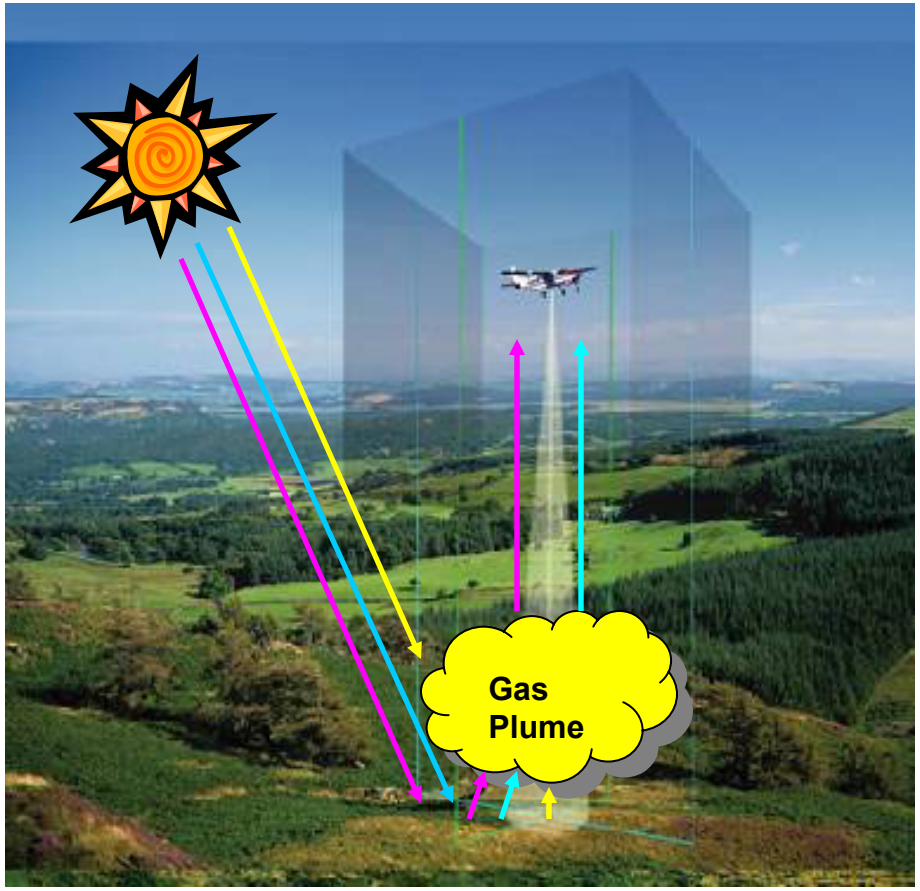
8:34	8:38	8:50	9:00	9:10	9:22	9:30	9:51	9:56	10:00	10:02	11:10	12:00
200	200	200	200	200	200	200	200	200	200	200	200	200
210	210	210	210	100	100	210	210	100	100	100	100	100
850	850	850	850	430	430	430	430	430	430	430	430	430
5000	5000	5900	5900	5900	5700	5700	5700	5700	5700	5700	5700	5700
0	20000	20000	20000	20000	20000	20000	20000	20000	0	3000	0	0
800	800	800	800	800	800	800	800	800	800	800	800	800
2200	2200	2200	4000	4000	4000	4000	4000	4000	4000	3800	3800	3800
210	210	210	210	100	100	210	210	100	100	100	100	100
		1447_1455; 1459-1504										
				1508_1512; 1517_1522								
						1526_1531; 1534_1541						
							1545_1553; 1557_1601					

Overview of Airborne Remote Sensing of Gasses.

Gas Absorption:

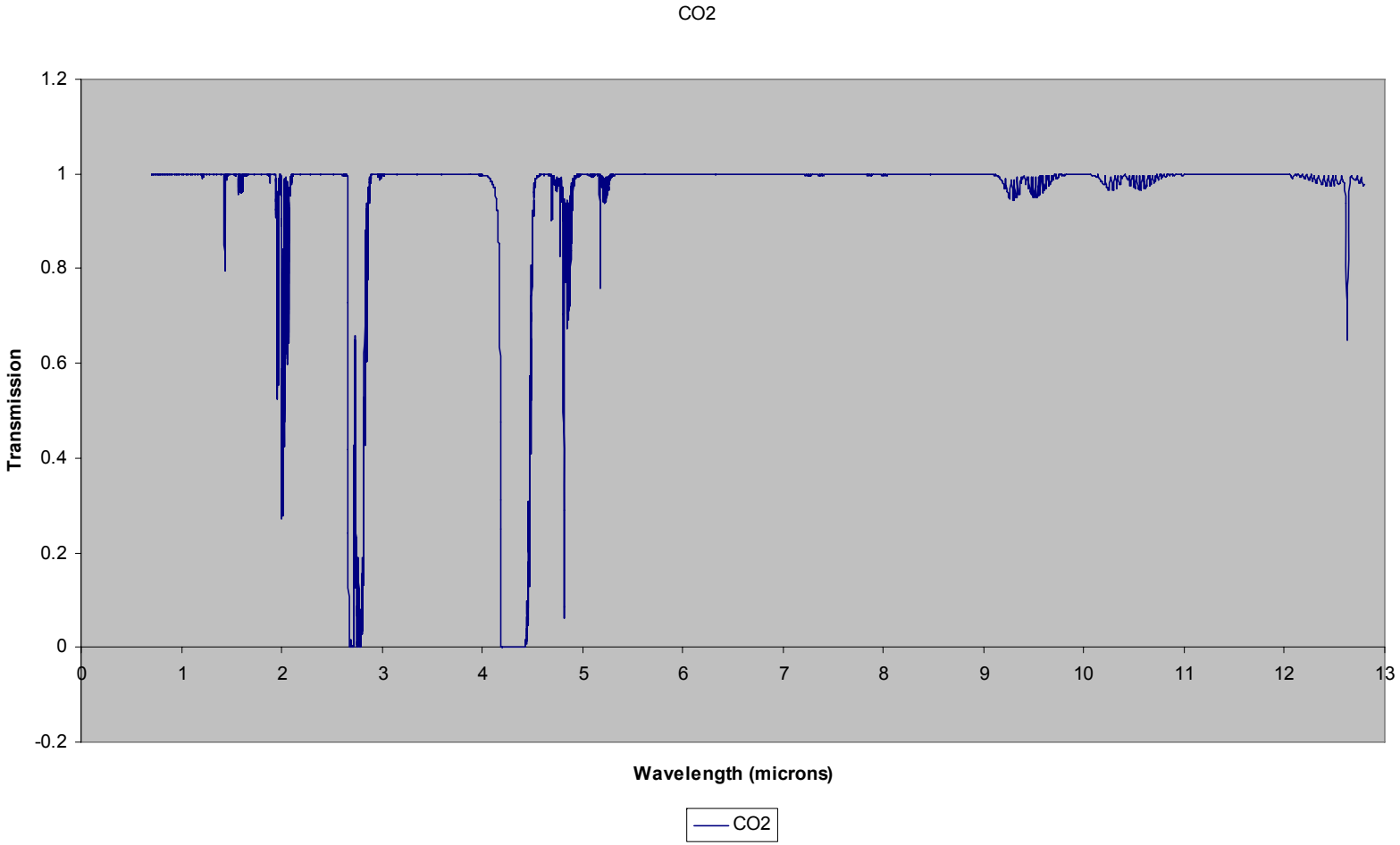
For passive sensors, such as MASTER, light from the sun is reflected and re-emitted from the ground as it passes through the gas plume.

All molecules absorb light in very discrete and narrow wavelength bands of visible, infrared, and thermal light. By focusing on these bands of absorption, we can watch and predict how much less energy reaches the sensor over a gas plume as opposed to an unaffected area.



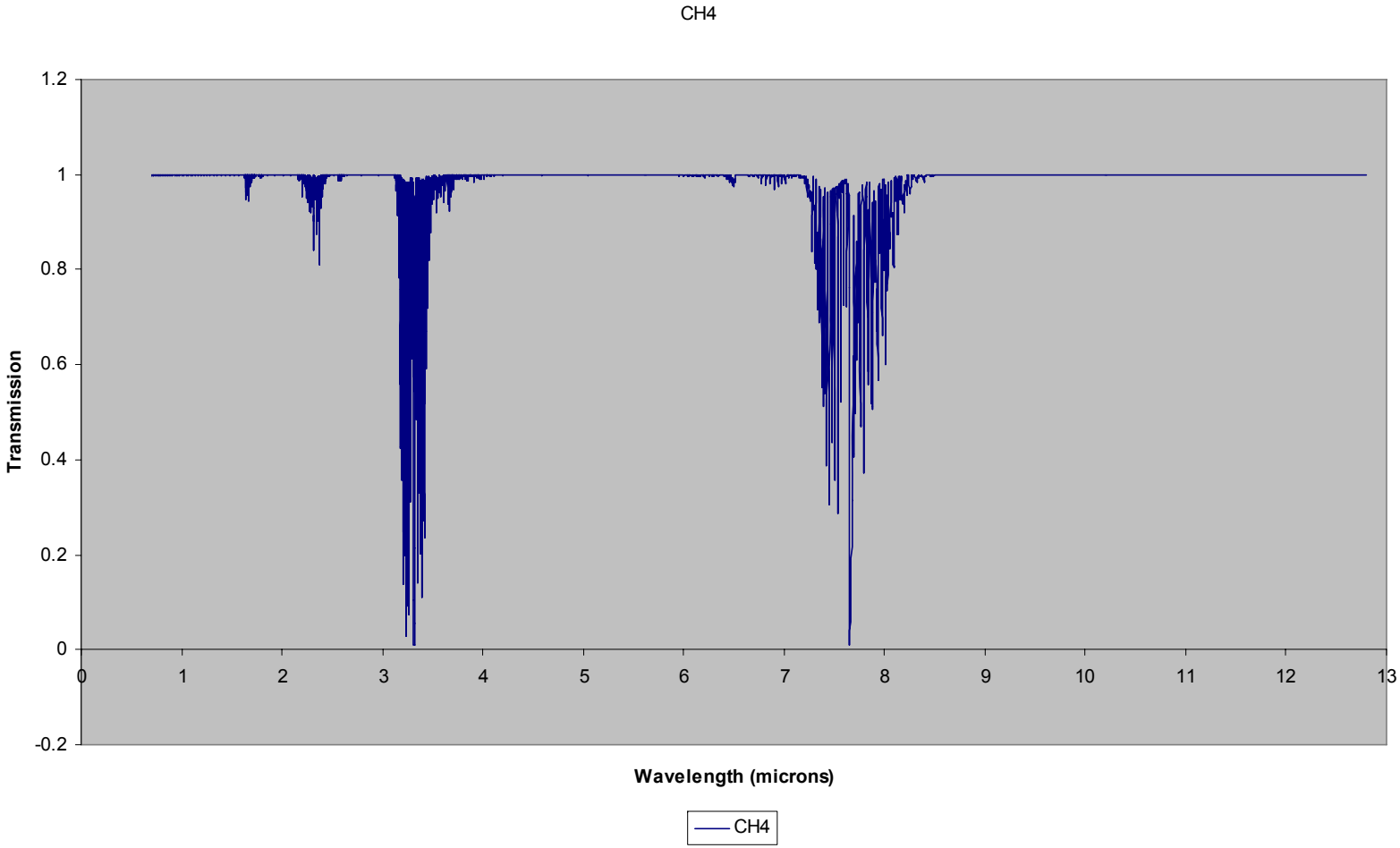
Original Photo taken from: http://www.netl.doe.gov

Key wavelength absorption bands for CO2
2.06um, *4.3um, 4.8um: (MASTER Band coverage: 19-20, *33-35, 37)



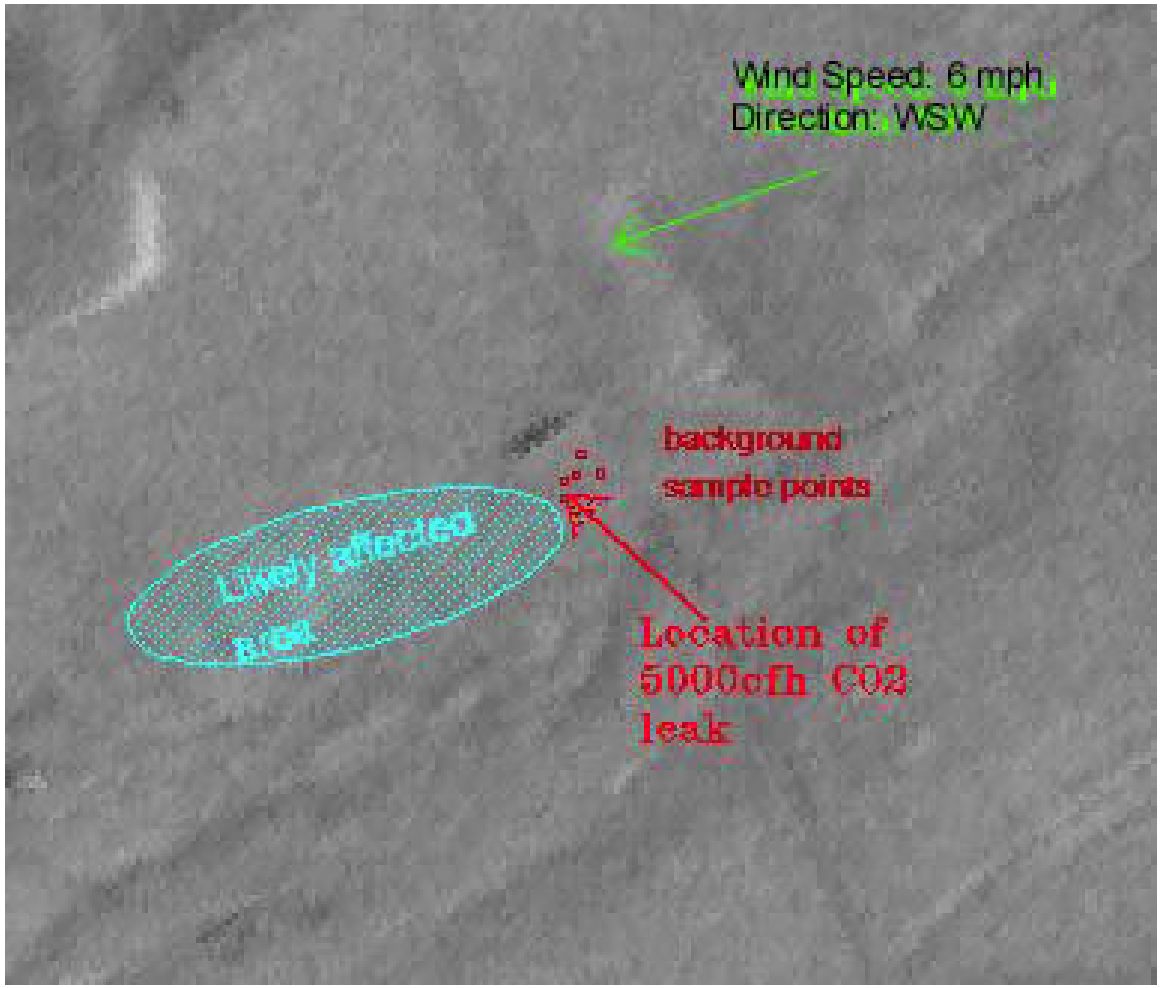
Atmospheric modeling with Modtran using PCmodwin reveals the absorption spectra of CO2 for 3000 meters of atmosphere at 380 parts per million CO2 at sea level.

Key wavelength absorption band for CH4: *2.36um; (MASTER Band coverage: 24-25)



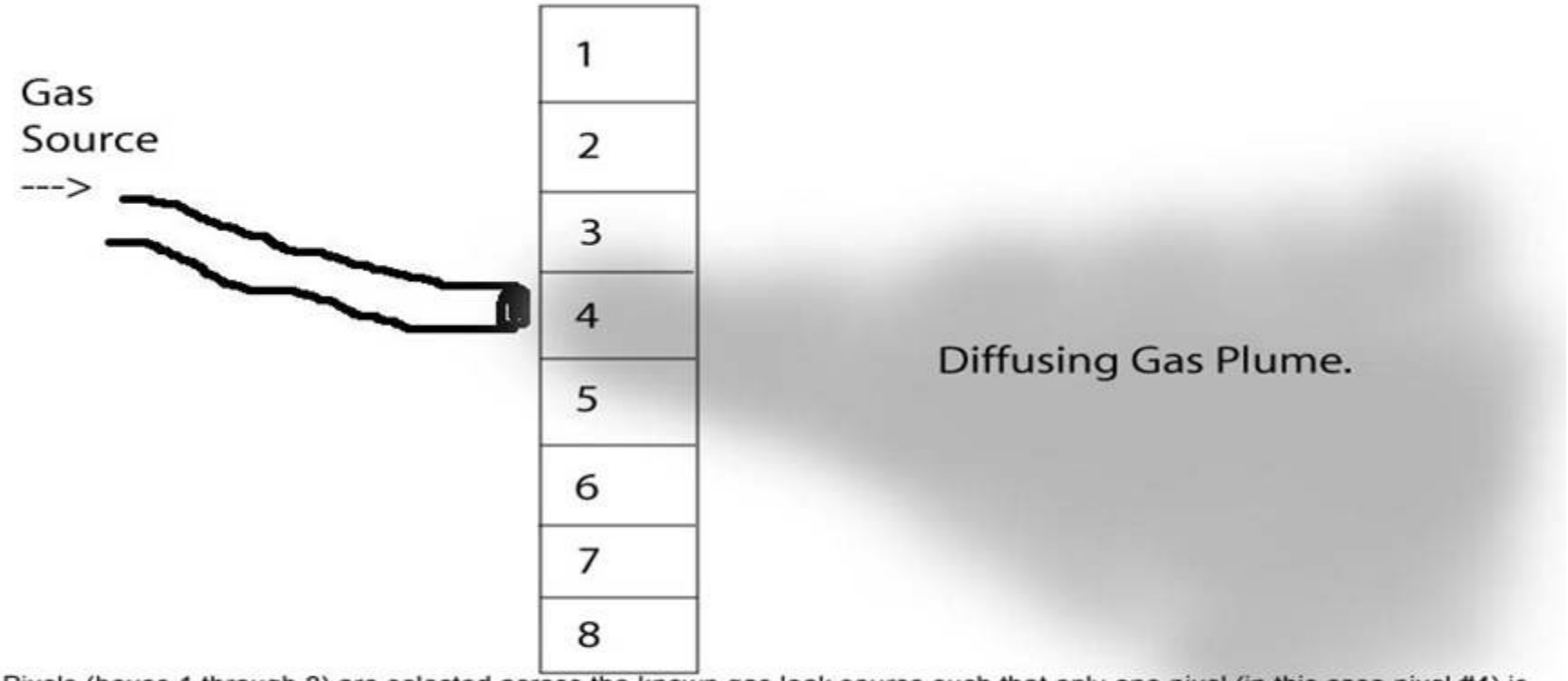
Atmospheric modeling with Modtran using PCmodwin reveals the absorption spectra of CH4 for 3000 meters of atmosphere at 1.7 parts per million CH4 at sea level.

CO2 Analysis: 5000cfh Leak (Site P1 large tank truck)



Site P1:
Gas- CO2
Rate (planned)- 5,000cfh
Rate (actual @ time of flight)- 4,000cfh

The Pixel Subtraction Technique compares nearby pixels in the image to the pixel of a known gas source.

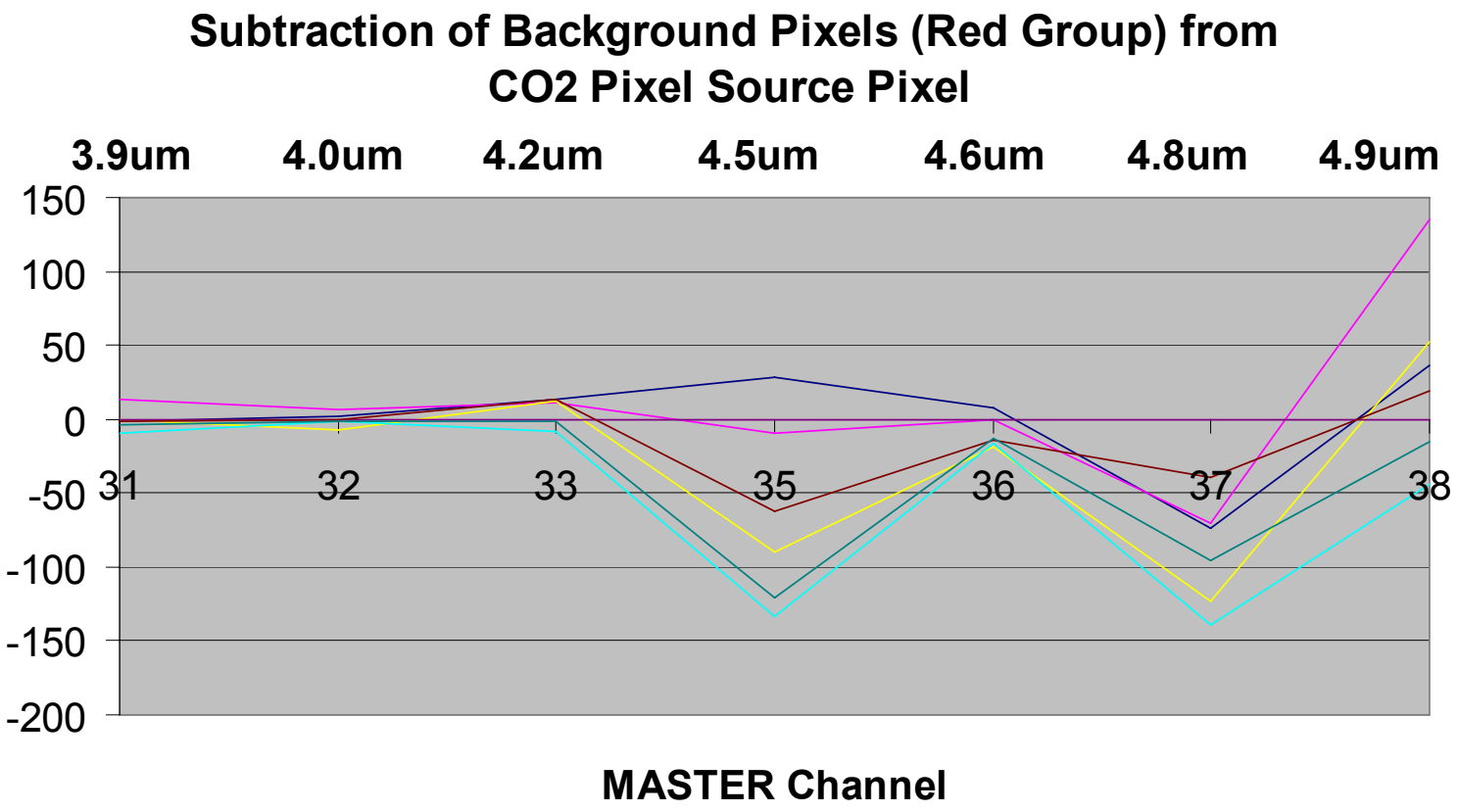


Pixels (boxes 1 through 8) are selected across the known gas leak source such that only one pixel (in this case pixel #4) is likely to be affected by the drop in light transmission which is characteristic for these gasses.

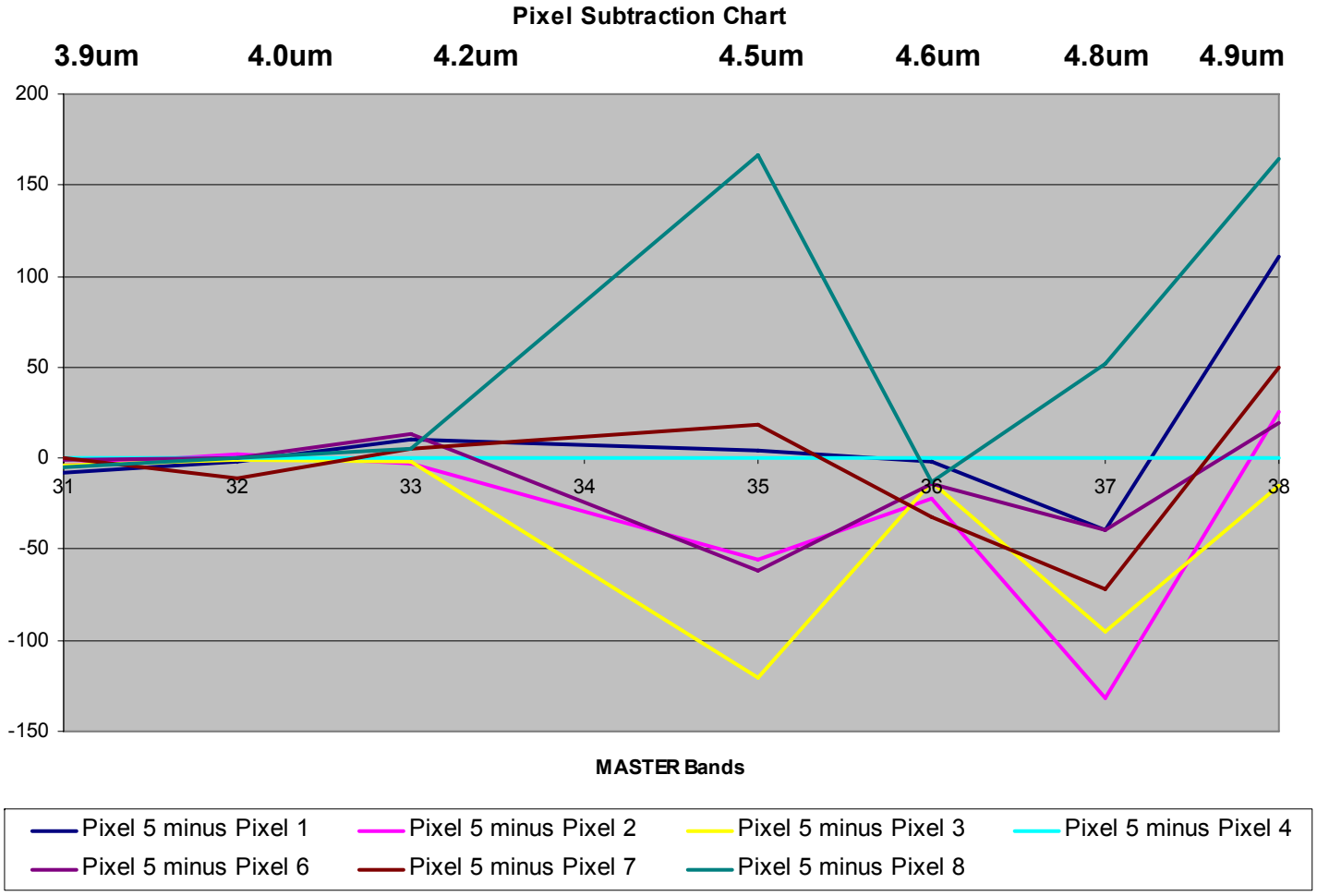
Therefore, by subtracting any of the other pixels from the "key absorption pixel" (for instance; Pixel 8 minus Pixel 4) we should get a negative number result. For example, if the radiance at Pixel 4 is 100, and the radiance at pixel 8 is 250, then Pixel 4 minus Pixel 8 (100-250) will equal -150.

However, one significant flaw to this process is the effect of turbidity near the gas source which may cause unpredictable local minimums and maximums in concentrations.

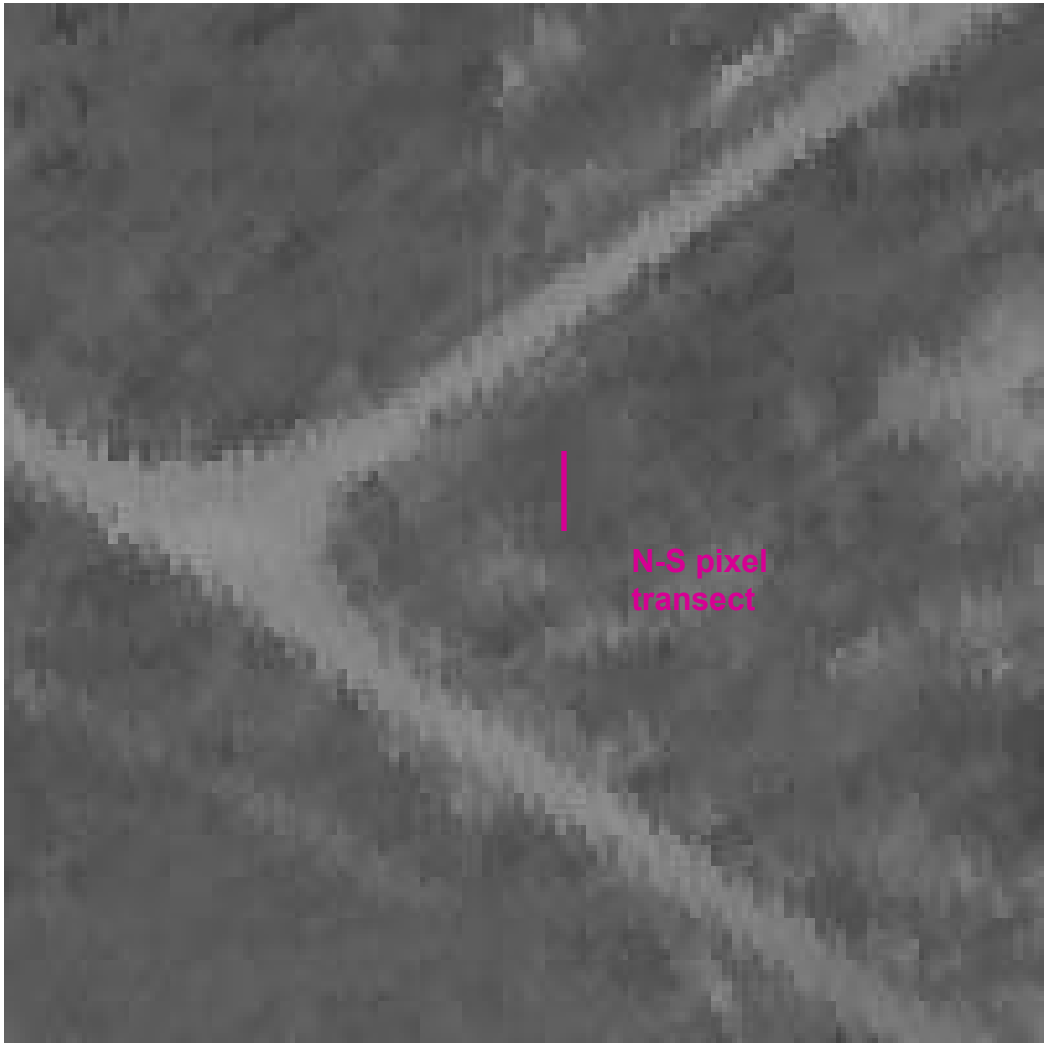
Divergence of radiance shows absorption of CO2 from release: 5000cfh Leak (Site P1)



CO2 Analysis: 5000cfh Leak (Site P1) Using 4.3 micron band 35 and 37 absorption and N-S transect pixel line.



CO2 Analysis: 800cfh Leak (Site 4) Cold



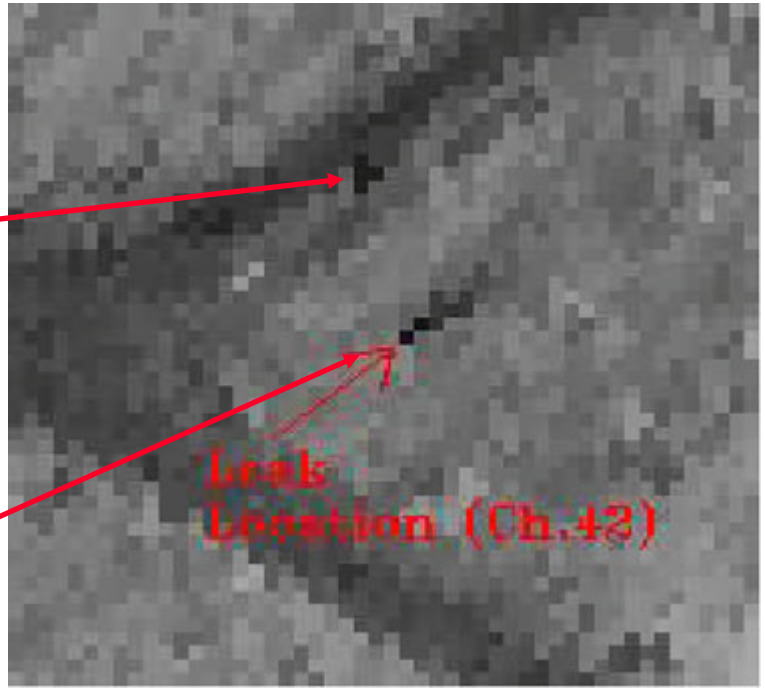
Site 4:

Gas- CO2

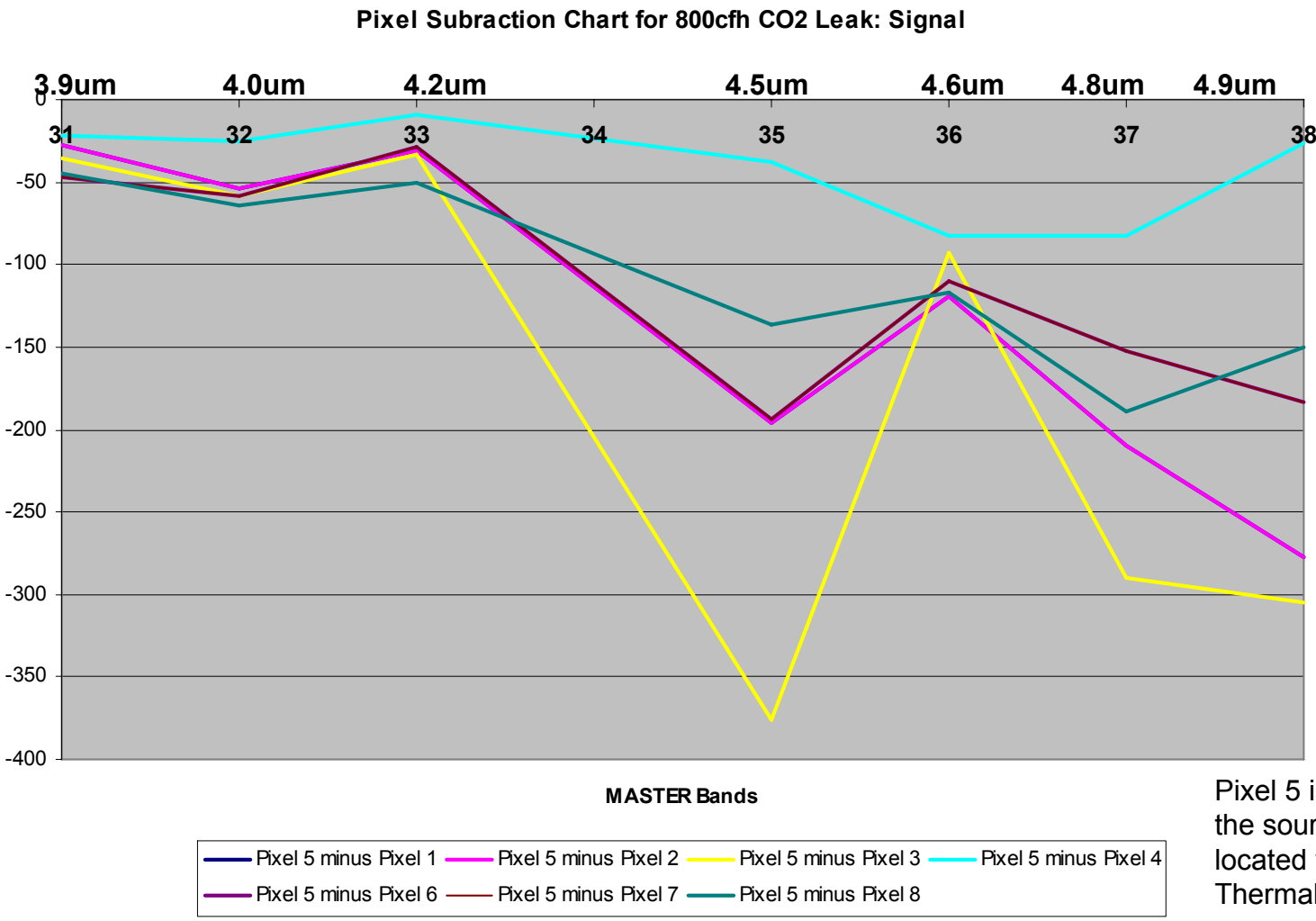
Rate (planned)- 800cfh

Rate (actual @ time of flight)- 20,000cfh

Cold objects in the thermal image are tank trailer and gas plume at Site 4:

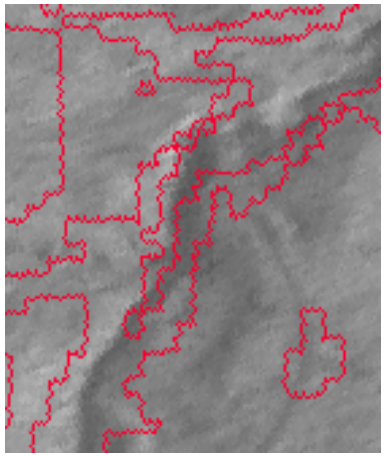


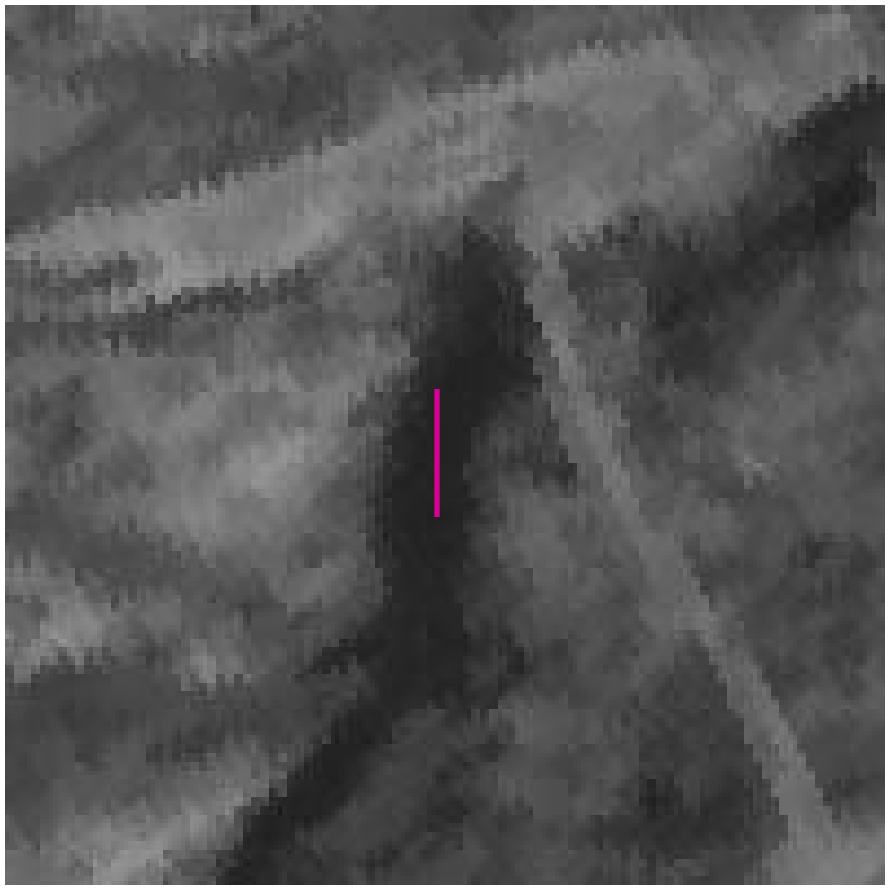
CO2 Analysis: 800cfh Leak (Site 4)



Pixel 5 is directly over the source. Source located via GPS and Thermal image.

CO2 Analysis: 300cfh Leak (Site P5)



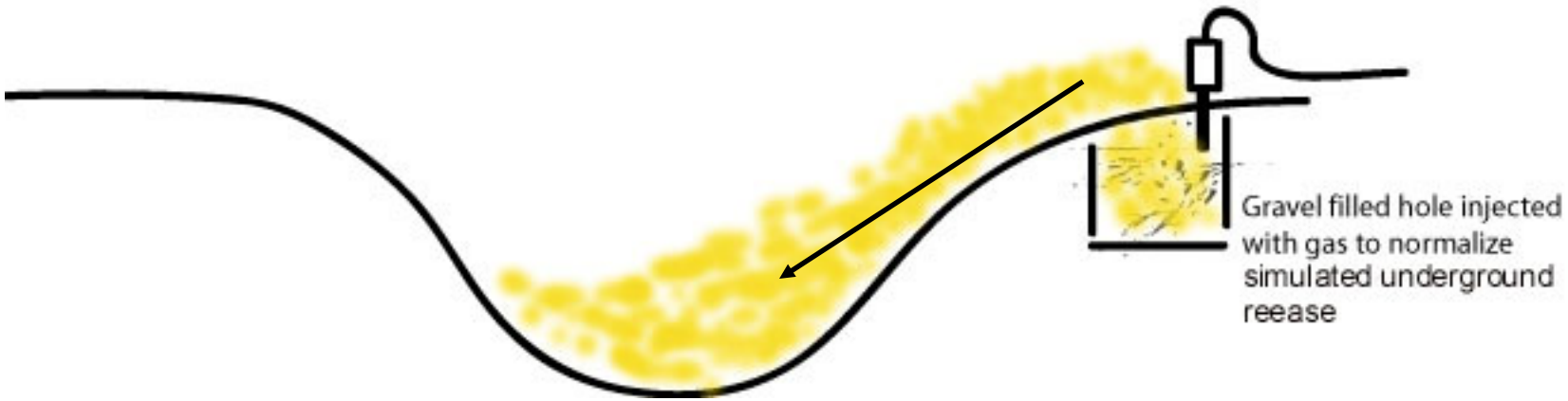


Site P5:
Gas- CO2
Rate (planned)- 300cfh
Rate (actual @ time of flight)- 200cfh

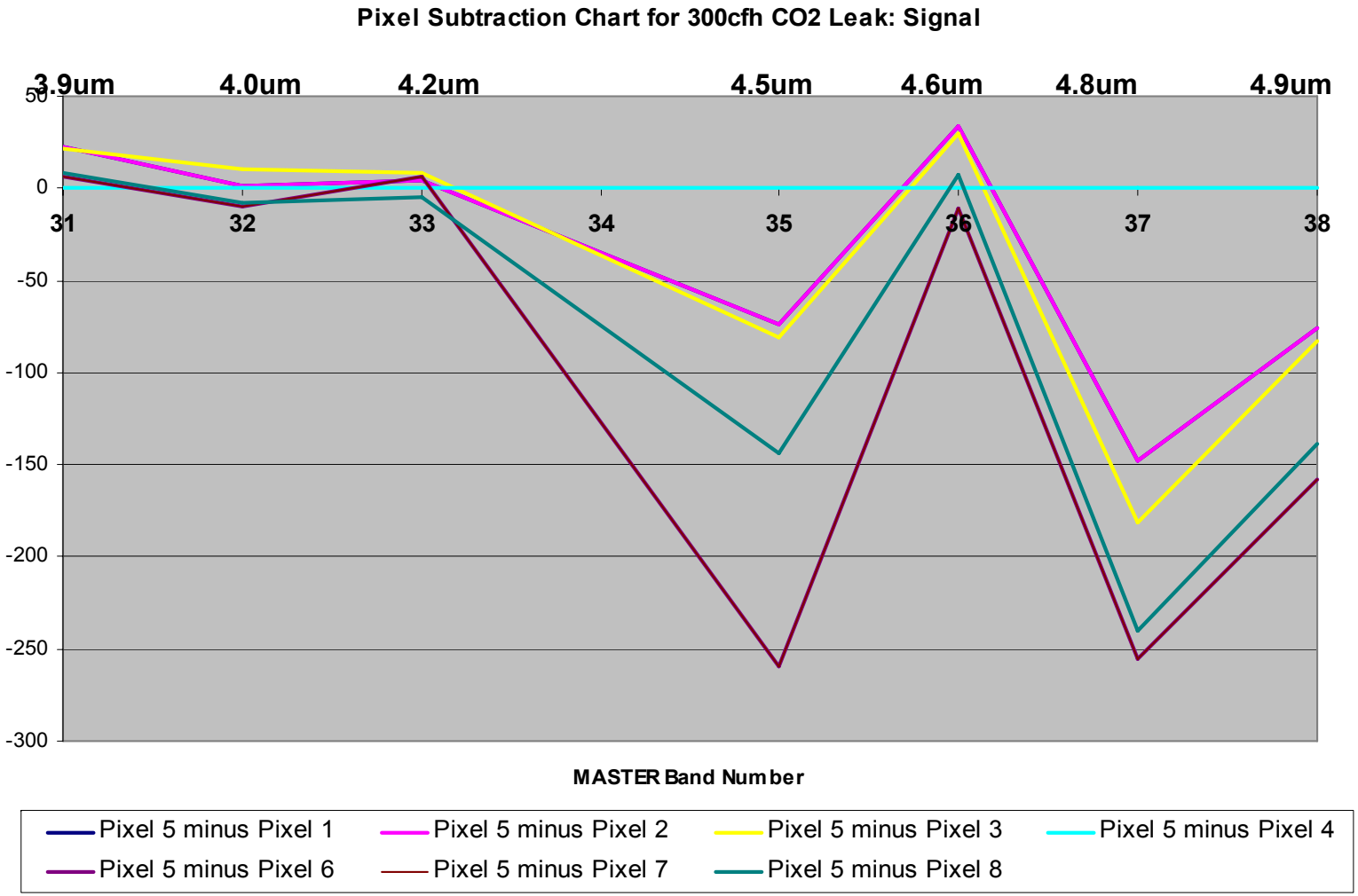
How does Pooling occur, and what affect might it have on MASTER.

Heavier than air gasses will flow downhill due to gravity. If there is a topographic depression this gas can collect and create a thicker than normal "pool" of gas.

In terms of an imaging spectrometer, this gives the illusion that there is more gas coming from the leak than is actually being emitted.



CO2 Analysis: 300cfh Leak (Site P5) Pooling?



MASTER vs. Modtran 4.0 Atmospheric Model

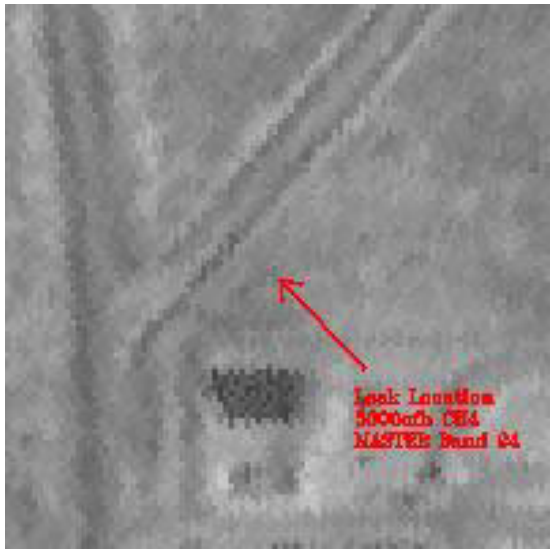
Using the atmospheric modeling software "Modtran", it is possible to get a reasonable expectation value for the concentrations of gas we are releasing, but without pooling.

The values presented here for the release site concentrations have been calculated 2 meters from the source, and averaged in the atmospheric column per meter in height off the ground. These numbers also assume that CO2 is well mixed above about 1m.

	Release Rate	Mixing ratio	Band 20		Band 35		Band 37	
Site ID	cfh	ppmv	detected	modeled	detected	modeled	detected	modeled
P1	4000	502	none	2%	18%	11.5%	37%	3%
4	20000	572	18%	3%	28%	10.5%	30%	4%
P5	200	492	none	2%	38%	16%	55%	2.5%

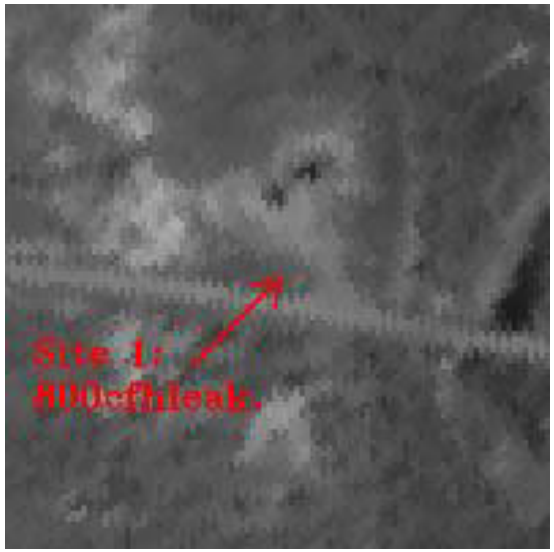
CH4 Analysis: There are four CH4 leak sites @ RMOTC, but we saw absorption only at Site 5.

5

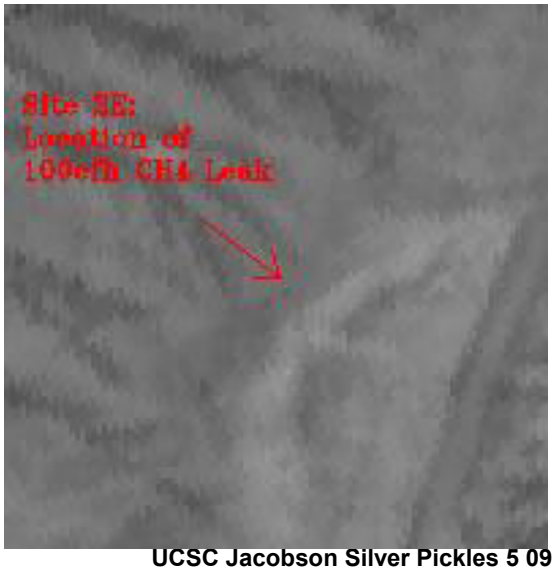


P3

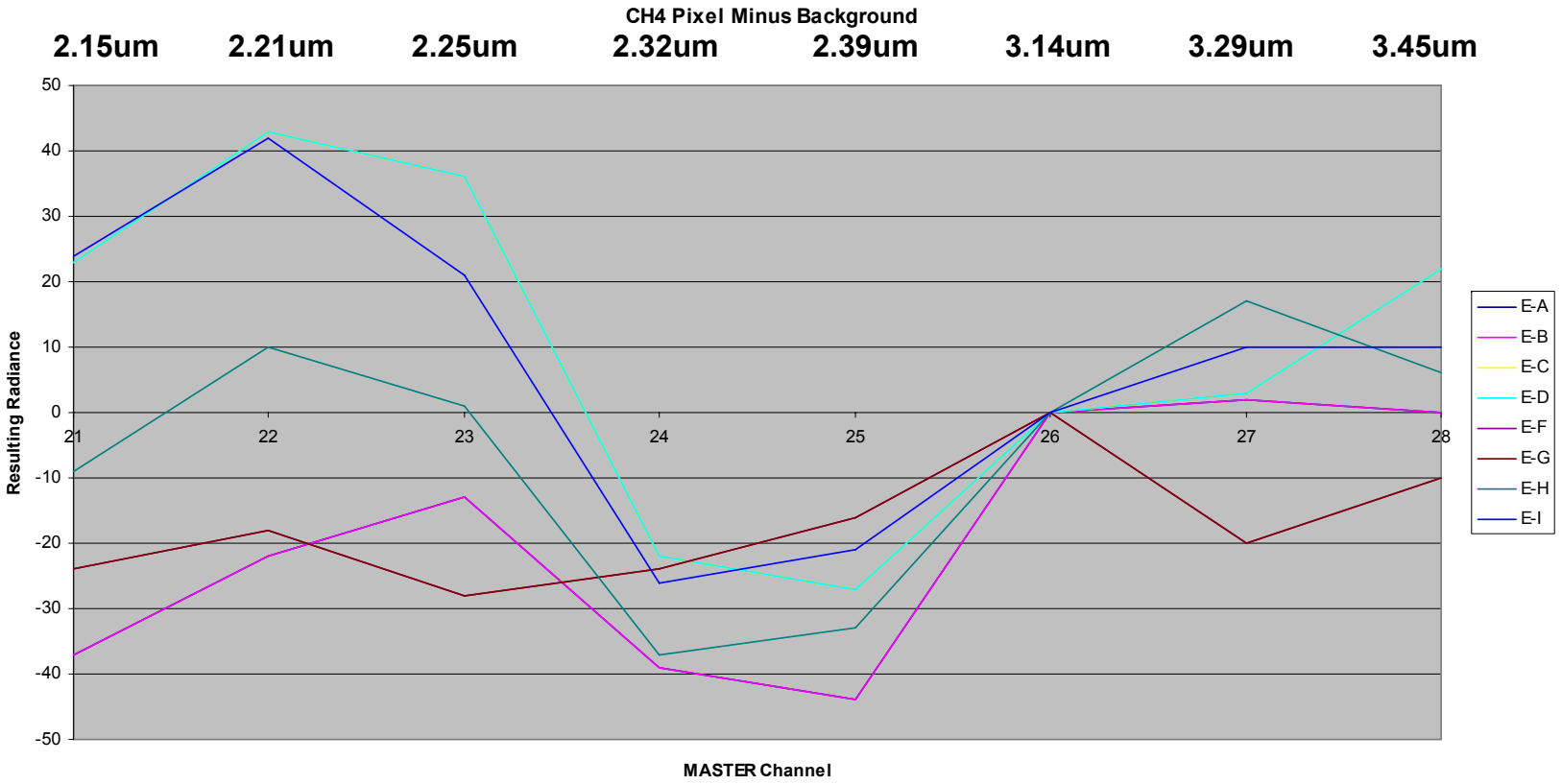
1



2E



‘Site 5’ was not only the highest output leak for CH4 onsite at RMOTC, but it was also the only site to give an applicable response in the low-altitude flight.



CH4 absorption may be more useful than CO2 absorption.

- The estimates currently are that this experiment increased gaseous CH4 concentrations 2m from the source up to 98,500 ppmv (Site 5); 13,800 ppmv (Site 1); 7,430 ppmv (Site P3); and 1,730 ppmv (Site 2E).

- The CH4 response may be more reliable than the CO2 response because of the limited variability and quantities that exist naturally in the atmosphere (1.7ppmv CH4 versus 380ppmv CO2).

CO2 and CH4 remote sensing next steps

- Continue modeling studies using MODTRAN software
- Reanalyze previous hyperspectral imagery taken of CH4 gas releases at RMOTC NPR3 for CH4 detection possibilities, using improved methods that we have developed in this project
- Calculate from this data the probably sensitivity of MASTER for detection of gaseous CO2 and CH4
- Final report will be available in December ’07

Where do we go from here?

- The natural evolution of a study such as this is not only to refine the ability to map these gasses from airborne sensors, but to also do so from a satellite sensor platform.

- The Orbiting Carbon Observatory (OCO) is a NASA Earth System Science Pathfinder Project (ESSP) mission designed to make precise, time-dependent global measurements of atmospheric carbon dioxide (CO2) from an Earth orbiting satellite.

- "Using a space-based platform, OCO will collect a far greater number of high resolution measurements (than a ground based measurement network) which in turn will provide the distribution of CO2 over the entire globe."

Web Sites and Resources

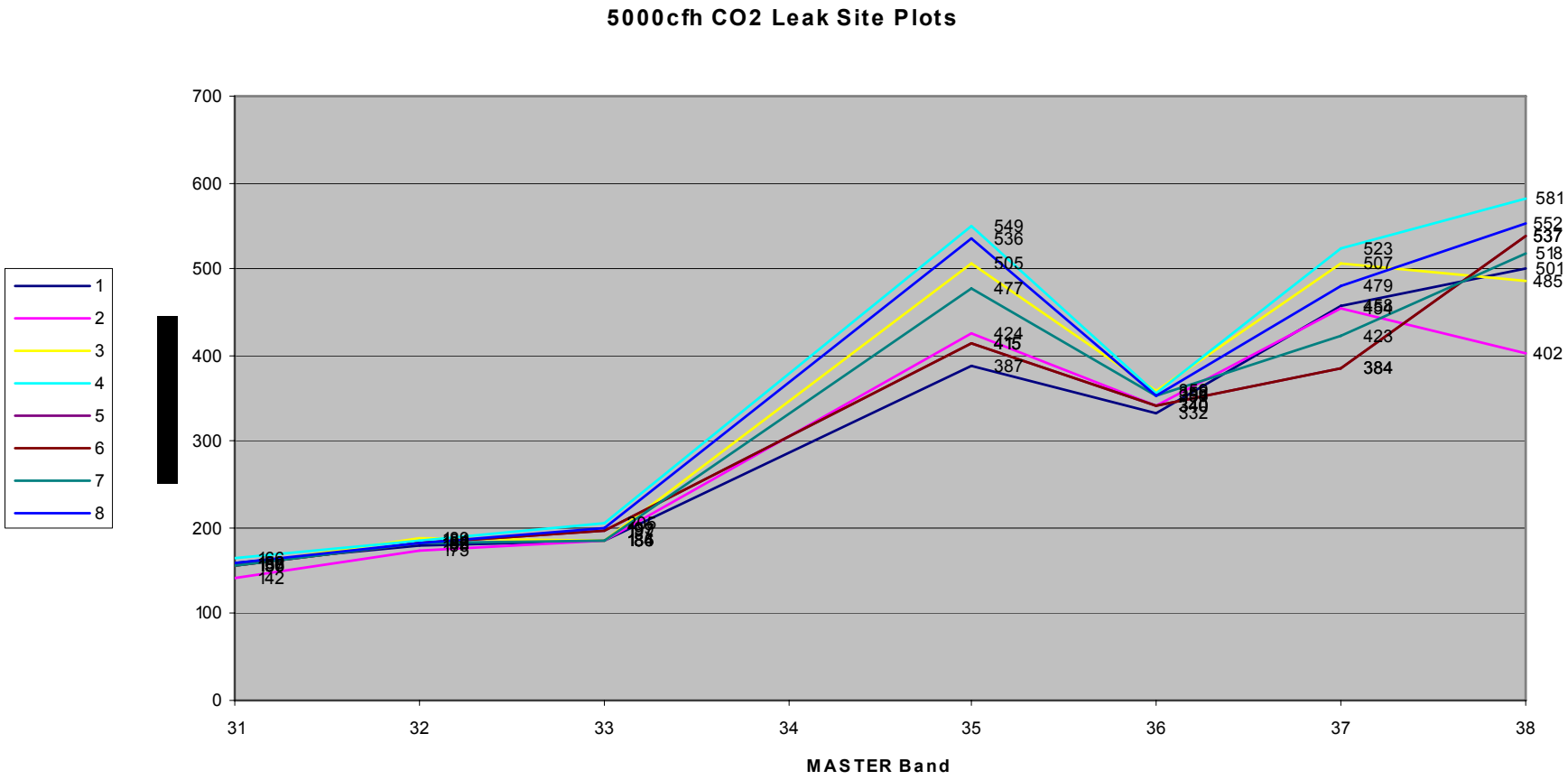
- **The Center for Remote Sensing at University of California Santa Cruz** http://emerald.ucsc.edu/~hyperwww/
- **Additional reading of interest**
  - S.J. Hook et al. “The MODIS/ASTER airborne simulator (MASTER) – a new instrument for earth science studies". Remote Sensing of Environment 76 (2001) 93-102.

- **Contact us for more information**
  - **James Jacobson (805) 637-4365** jacobson@pmc.ucsc.edu
  - **Bill Pickles 925 519 5957** pickles@pmc.ucsc.edu

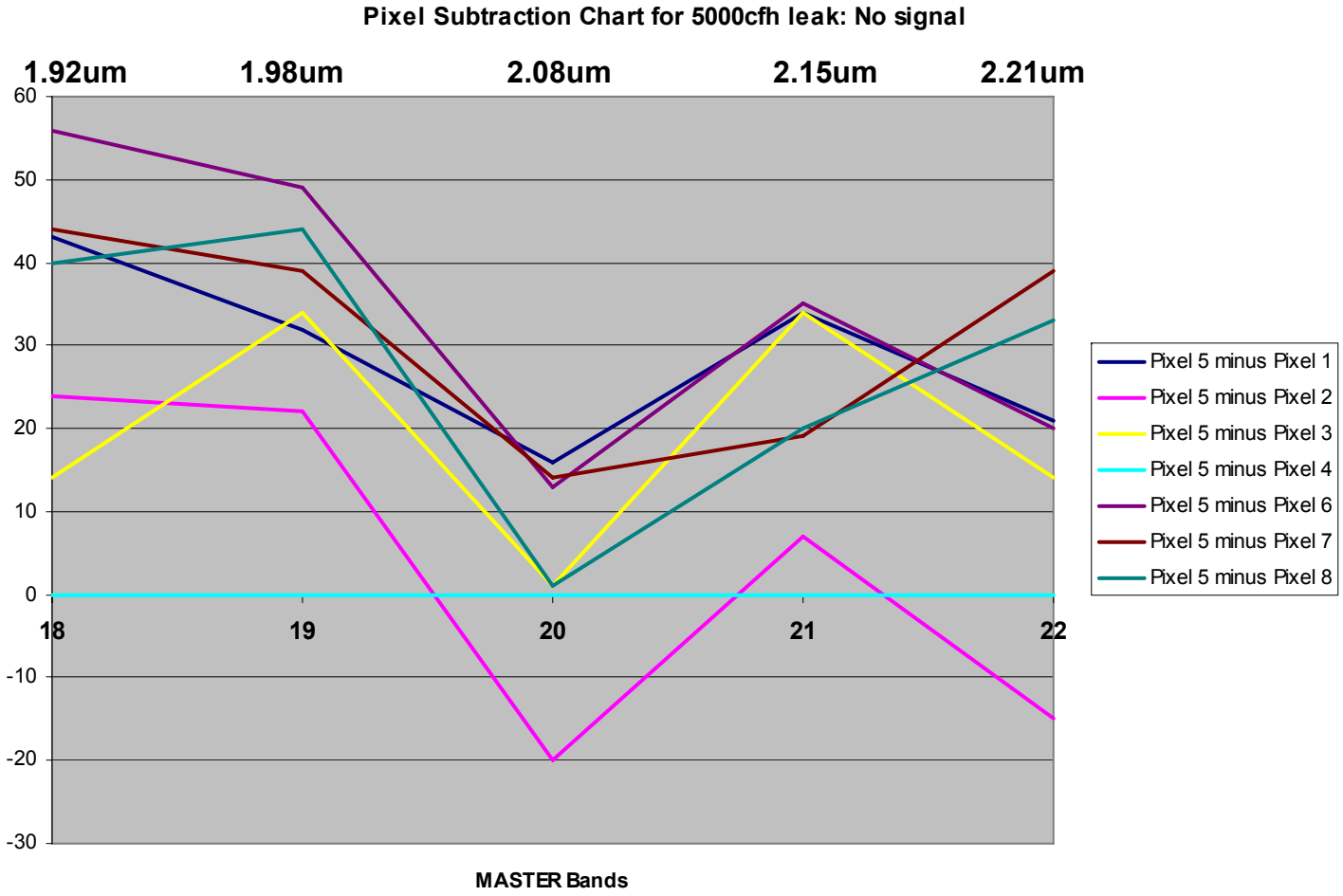
END

- **END**

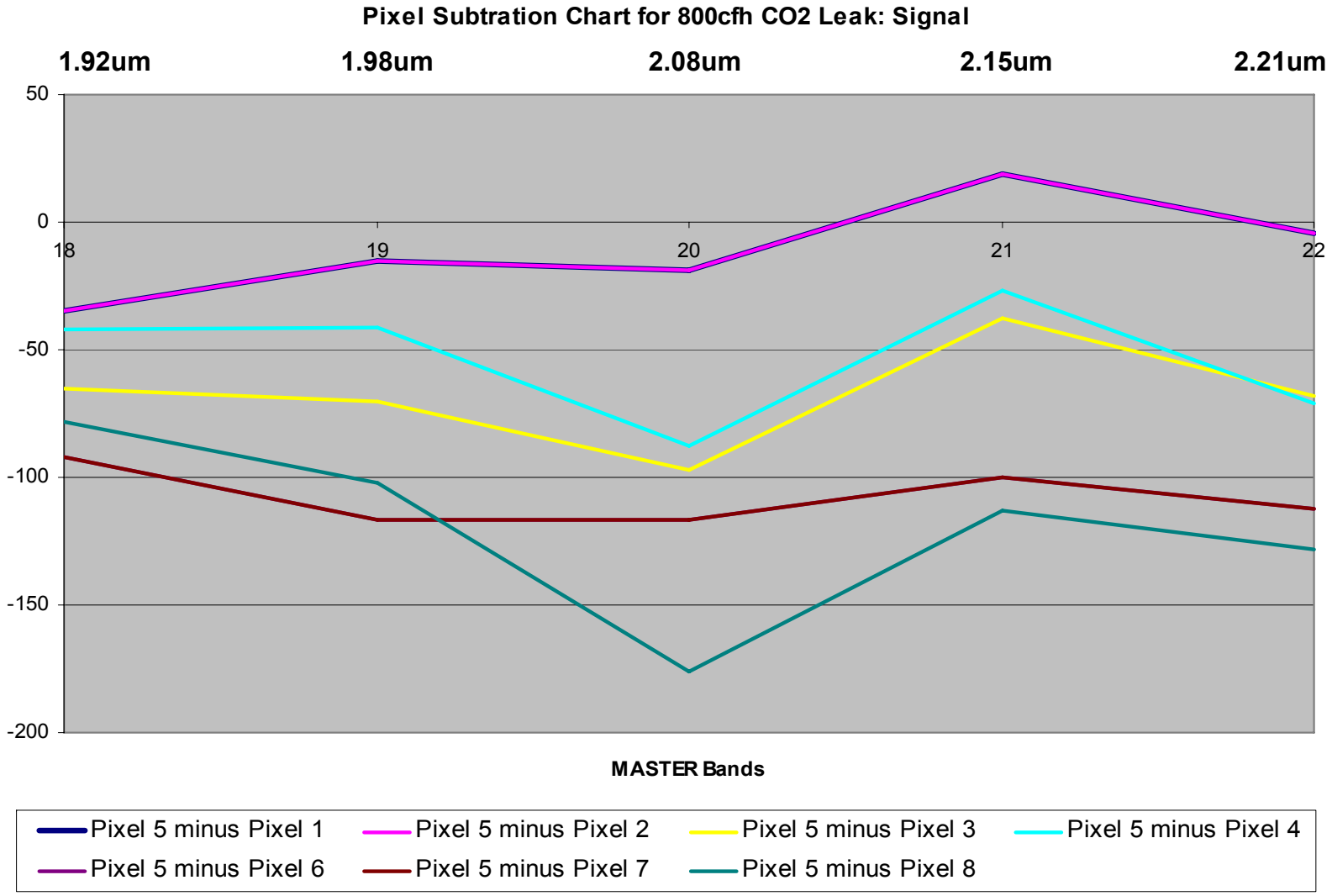
Digerence shows absorption



CO2 Analysis: 5000cfh Leak (Site P1) using 2.06 micron absorption band 20 and N-S transect pixel line.



CO2 Analysis: 800cfh Leak (Site 4)



CO2 Analysis: 300cfh Leak (Site P5)